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Towards a climate change adaptation strategy for national parks: Adaptive management pathways under dynamic risk

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ABSTRACT

Government seeks to manage public protected areas, such as national parks, to conserve high-quality wildlife habitats and provide essential ecosystems services at risk of permanent damage or extinction from climate change. The complexity of the organizational structure required to deliver this breadth of functions, coupled to uncertainty surrounding the onset and severity of climate impacts at local scale, impedes planning for climate change. This paper describes the development of an adaptation planning tool and its application in a pilot planning process for the National Parks and Wildlife Service, the agency of the New South Wales (NSW) Government (Australia) responsible for management of national parks and public conservation reserves. The process involved close engagement in knowledge co-production in participatory workshops, and employed two complementary techniques, adaptive pathways and risk assessment. It successfully elicited tacit knowledge of agency staff about the range of interventions available, the need for management practices to evolve, and of discontinuities in management pathways in a dynamic risk environment. Findings suggest that management effort across the NSW reserve system will increase as climate risk rises. Consequently, government will need to respond to increased demand for resources, for better targeting of those resources, and for management innovation in how resources are deployed to support adaptation that is both anticipatory and transformative.

1. Introduction

The effects of anthropogenic climate disruption are expected to be wide-scale and devastating for ecosystems and the services they provide to society (Parmesan and Yohe, 2003; Cardinale et al., 2012; Urban, 2015; Grimm et al., 2016). While evidence is mounting that ecosystems are already affected (e.g. Hughes, 2000; Pecl et al., 2017), there remains uncertainty about the onset and severity of some impacts, which is problematical for planning societal responses (for example sea level rise: Moser, 2005; Spirandelli et al., 2016).

Public protected areas, such as national parks, are specifically managed for biodiversity conservation of native species and their habitats. Typically, biodiversity conservation is seen as a public good that offers benefits at a range of temporal and spatial scales (Perrings and Gadgil, 2003), and therefore traditionally falls to government to service (Lockwood, 2010; Berkes, 2007). Public protected areas that contain high-quality wildlife habitats and provide essential ecosystems services at risk of permanent damage or extinction from climate change will require management intervention to maintain their biodiversity values (Cimato and Mullan, 2010). Management that seeks to limit the future damage from climate impacts rather than mitigate the underlying causes of climate change (i.e. greenhouse gas emissions) is generally defined as anticipatory adaptation and is a distinct process from the autonomous adaptation that occurs in biological systems leading to ecosystem change (Fankhauser et al., 1999; Smit and Pilifosova, 2003). While the effects of climate-induced species changes do not necessarily involve a decline in ecosystem biodiversity (Vellend et al., 2017), the normative intent in national parks is to conserve the diversity of native species rather than of species diversity per se. The focus on native species has led recently to the development of approaches to conservation interventions that recognise the inevitability of ecosystem change under future climate (Dunlop et al., 2013; Jones et al., 2016). For ecosystems, dynamic approaches to intervention have been suggested that accommodate ecological change and biodiversity loss, that remain relevant and feasible under a range of future trajectories, and that seek to conserve multiple societal values (Cimato and Mullan, 2010; Dunlop et al., 2013).

In New South Wales (NSW) Australia, management of national

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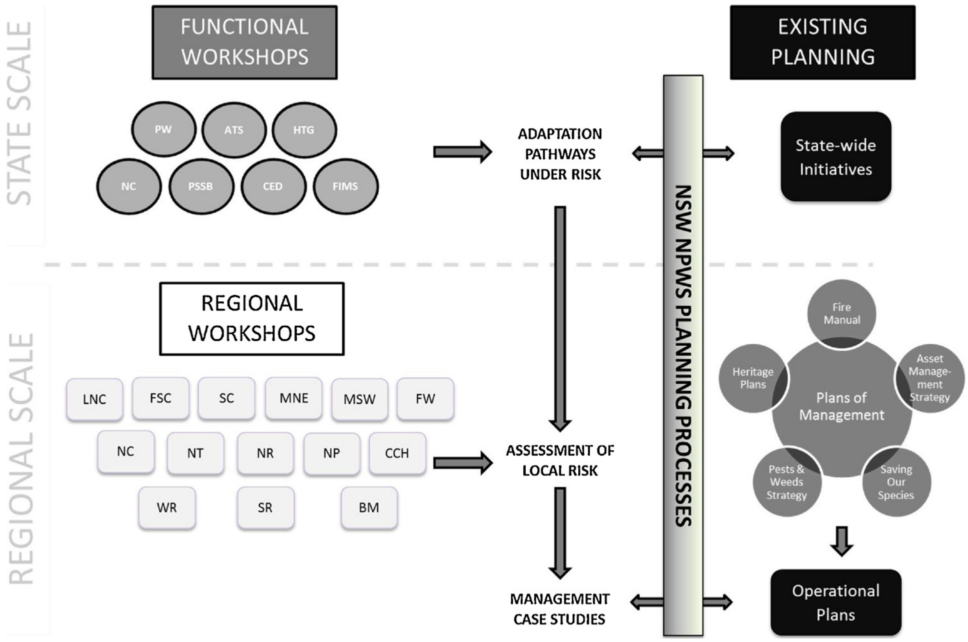

Fig. 1. Interrelationships among type of workshop (functional area and regional), scale (state, regional and park) and existing policy and planning processes (e.g. Plans of Management (POMS)) in the pilot of a climate adaptation planning process for NSW NPWS. Letters within symbols designate a functional area or region for seven functional areas or 14 regions respectively. Functional areas were Pests and weeds (PW), Nature conservation (NC), Strategy and services (ATS), Park assets management (PSSB), Heritage (HTG), Customer experience (CED) and Fire and incident management (FIMS). Regional locations were Lower North Coast (LNC), North Coast (NC), Western Region (WR), Far South Coast (FSC), Northern Tablelands (NT), South Coast (SC), Northern Rivers (NR), Southern Ranges (SR), Metropolitan North East (MNE), Metropolitan South West (MSW), Northern Plains (NP), Far West (FW), Central Coast Hunter (CCH), and Blue Mountains (BM).

parks and public conservation reserves is performed by the NSW National Parks and Wildlife Service (NPWS) (New South Wales Government, 2016). Government has a distinct role in climate adaptation, which includes adaptation of its own operations and creation of conditions that encourage adaptive action in the community (Brooks and Adger, 2005). Management of contemporary public protected areas performs a range of functions, in addition to conservation of native biodiversity (Ayres, 2016). The functions of the NPWS range from fire and incident management (often as a statutory fire authority), pest and weed control and maintenance of built assets (tourist centres, roads and fire trails, signage) to provision of tourism and public amenity (recreation and nature experiences) and protection of cultural heritage assets (historic buildings and sites, Aboriginal sites of significance). Some of these functions may be only indirectly related to conservation of native species. In addition to coping with climate impacts across a range of NSW climatic zones and landscapes (Jacobs et al., 2016; New South Wales Government, 2015a,b), NPWS has to plan adaptive actions for these multiple functions that will be variously affected by changing climate.

Government agencies, in common with other types of organisations, are subject to a range of barriers that restrict the planning, implementation and options for adaptation actions (Moser and Ekstrom, 2010). These barriers include conflicting timescales; substantive, strategic and institutional uncertainty; institutional crowdedness and institutional void; institutional fragmentation; lack of awareness and communication, motives and willingness to act; and, lack of resources (Biesbroek et al., 2013). Barriers can also form complex interdependencies that stymie organizational change (Eisenack et al., 2014). An assessment of the barriers to adaptation for NPWS is beyond the scope of this paper. However, while recognizing that significant planning has occurred within specific functional areas (e.g. fire and incident management), it is likely that the complexity of NPWS's organizational structure and the breadth of its functions coupled to uncertainty surrounding the onset and severity of climate impacts across operational geographies have impeded whole-of-agency strategic planning for climate change. These issues often elicit a collective view that the task is 'too big to tackle' (Moser, 2014; Pidgeon and Fischhoff, 2011). Under such conditions innovative approaches are needed that implicitly recognise uncertainty through the integration of adaptive planning and climate risk management (Lawrence and Haasnoot, 2017, Woodruff, 2016; Walker et al., 2013). Jones and Preston (2011) mapped the range of approaches to adaptation planning in two dimensions according to their style of engagement with stakeholders (top down versus bottom up) and how they deal with time (predictive versus diagnostic). However, they suggest approaches that combine these orientations and incorporate multiple perspectives as offering greater flexibility in complex situations.

In addition to the generic characteristics of assessments, a number of specific techniques have been suggested as useful additions to adaptation planning and assessment approaches to ensure uncertainty is explicitly considered. These techniques include robust decision making (Lempert et al., 2006), real options analysis (Dobes, 2008), and dynamic adaptive policy pathways (Haasnoot et al., 2013). In complex 'real world' situations, such as adaptation planning for a multi-functional government agency, selection of techniques must be made pragmatically, often requiring blending of theory and practice in bespoke, contextual processes that account for wide variations in available data, staff knowledge and business systems, and that simultaneously seek to build organizational adaptive capacity (e.g. Jacobs et al., 2014, 2015).

This paper describes the development of an adaptation planning tool and its application in a pilot climate adaptation planning process for the NSW NPWS. The tool and process aimed to address the complex operational realities of the organisation, incorporate uncertainty into the assessment process, engage participants (NPWS staff) to help overcome barriers to adoption, and build capacity to use outputs in existing agency planning processes.

2. Methods

Two series of workshops were conducted consecutively with participants drawn from a broad range of policy, planning and operations tasks across NSW NPWS (Fig. 1).

2.1. Functional area workshops

The first series consisted of seven workshops with 'functional areas' of the agency. These functional areas are tasked with centralised policy and planning at state and regional scale. The purpose of these workshops was to elicit information on the broad suite of management options available to each functional area in response to the major impacts of a changing climate. This information would then be synthesised into

Table 1
NSW NPWS functional area groupings, their role in the agency and number of participants at functional area workshops.

Functional area	Role in agency	No. of workshop participants
Pests and weeds (PW)	Leadership, strategy, frameworks and coordination to support regional delivery of pest management programs.	10
Customer experience (CED)	Develop and manage publications, content, brand, programs and communications. Manage call centres, booking systems and oversee community partnership and volunteering. Plan and develop visitor experiences, including NPWS Visitor Centres, delivering visitor and student educational programs and coordinating integrated customer and visitor interpretation programs. Implement state-wide and regional tourism strategies; conduct visitor research; and coordinate and manage events and venues.	12
Heritage (HTG)	Aboriginal Heritage - provide state-wide, cross-government coordination and advice on Aboriginal heritage and Aboriginal Joint Management programs, strategies, policies, funding, projects and initiatives and deliver corporate programs and priorities. Historic and World Heritage - provide advice and support in planning and conservation works in relation to historic heritage sites, precincts, objects, collections and investigations. Provide input into policies, strategies and systems to support historic heritage management in parks. Coordinate projects, programs and reporting for World Heritage Areas on NSW NPWS parks.	17
Park Assets Management (PSSB)	Lead the development and implementation of asset strategies and initiatives for fixed and mobile assets within NPWS. Provide asset policy, asset management systems, lifecycle and value management and lead acquisition, maintenance and disposal programs for mobile and fixed NPWS assets. Support park operations and incidents through management of mobile fleet and radio communication assets and provide expert support for high risk operations.	8
Fire and Incident Management (FIM)	Lead the coordination and delivery of state-wide fire and incident preparation, planning, response and recovery. ('Incidents' include rescue of marine mammals, natural disasters such as storms or flooding, and chemical or hazardous spills)	12
Nature Conservation (NC)	Biodiversity and Wildlife - Provide leadership, strategy, frameworks and coordination to support regional biodiversity and wildlife activities (including threatened species) and implement wildlife programs on and off-park. Reserve Establishment - Plan, assess, acquire and reserve strategic lands within the national park estate and provide tenure and land information services. Landforms and rehabilitation - Deliver major rehabilitation programs and provide leadership, strategy, frameworks and coordination to support adaptive management across NPWS and regional delivery of environmental water, rehabilitation and geo-diversity programs.	15
Strategy and Services (ATS)	Strategy and Policy Team lead the development and interpretation of legislation, regulation and policy. Responsible for specialist support and integration services to NPWS and the Customer Service Division (CED). Lead strategic, operational and park planning across NPWS, including evaluating the effectiveness and outcomes of park management programs and ensuring compliance with environmental impact assessment and public health requirements. The Community and Stakeholder Engagement Team (CaSET) engages the community of NSW and stakeholders in the management, awareness and enjoyment of national parks.	27
Total		101

an adaption planning tool for use by operational managers at the park (sub-regional) scale. Each of the workshops began with brief introductory presentations on the aims of the project and a summary of climate projections for NSW (New South Wales Government, 2015a,b). The project lead investigators (a professional researcher and a government project manager) jointly facilitated workshop plenary sessions. A lead facilitator (researcher or government officer) and a scribe supported small group sessions. In small groups of about 4–8, workshop participants performed four main tasks:

(1) Define the responsibilities of functional areas (summarised in Table 1) to gain an understanding of the breadth of roles performed by NPWS.
(2) Visualise, as causal diagrams (Jonassen and Ionas 2008), the impacts of major climate drivers with a focus on changes in rainfall and temperature, expressed as both extreme events (such as storm cells and droughts) and incremental changes. Key event chains were extracted from the diagrams for a deeper consideration of the management actions undertaken by NPWS functional areas in response to specific impacts, and potential cross-dependencies with other climate actors within and external to NPWS.
(3) Develop an assessment matrix to understand how functional areas currently prioritise management actions with respect to levels of climate risk. Risk was defined as the product of the probability and consequence of an event (Hultman et al., 2010). The process allowed each functional area to frame risk heuristically in relation to its specific role and operations, particularly where risk assessment was not routinely incorporated in strategic planning of that group.
(4) Construct a matrix of adaptive pathways that incorporated the range of management options available to each functional area. A pathways approach was used because it enables flexible planning under deep uncertainty and helps prioritise adaptive actions in a dynamic risk environment (Kwakkel et al., 2015). This process involved assembling a comprehensive list of management options, ordering the list according to the degree of intervention associated with the action (for example, monitoring required less intervention than asset decommissioning), and the use of tacit knowledge (Nonaka and von Krogh, 2009) to determine the levels of risk at which each management action would be implemented and discontinued. For example, it may not be sensible to continue with repairs and maintenance to a built asset exposed to a high level of risk. In addition, participants suggested adaptations to the action that might occur as risk levels rose. For example, monitoring might change from low frequency, on-site inspection by staff to higher frequency, remote sensing with rising level of risk.

2.2. Regional workshops

The information from the functional area workshops was developed into a risk assessment tool which subsequently informed a series of regional workshops. These workshops were held with regional NPWS staff representing a broad range of roles at 10 locations covering 14 regions throughout NSW (Table 2). The initial workshop in the regional series was co-facilitated by researchers and government staff to test the process in a train-the-trainer setting. Thereafter, government project staff facilitated the workshops.

Table 2
Regions, locations and participation in NPWS regional workshops.

Regions	Roles represented	Number of participants
Far South Coast and South Coast /Depot Beach (FSC)	Strategic planning; fire management, area management, pest management, tourism, ranger, heritage, senior assets management, species recovery (shorebirds)	29
Central Coast Hunter and Lower North Coast / Newcastle (CC & LNC)	Area management, bushfire management, strategic planning, fire management, operations coordination, ranger, park planning, assets management, coastal science, Aboriginal heritage conservation, wildlife management	28
Southern Ranges /Jindabyne (SR)	Environmental management, ranger, tourism, strategic planning, fire management, pests and weeds management, field supervision, planning, regional management	28
Northern Plains / Narrabri (NP)	Strategic planning, area management, ranger, assets management, fire management, heritage.	18
Northern Rivers/ Byron (NR)	Ranger, area management, assets management, planning, 'Saving our Species' program management; heritage, planning. pest and weed management.	16
North Coast/ Coffs Harbour (NC)	Aboriginal heritage, regional management, threatened species management, ranger, fire management, area management, pest and weeds management, planning, program services delivery.	20
Metro North East and Metro South West/ Sydney (MNE & MSW)	Visitor and tourism management, historic heritage curation, pest and weeds management, planning, area management, strategic planning, assets management, park rehabilitation, biodiversity and wildlife management.	22
Blue Mountains/ Blackheath (BM)	Strategic planning, policy management, area management, ranger, assets management, fire management, Aboriginal heritage conservation, World Heritage conservation, retail management, pests and weeds management.	21
Western Rivers/ Griffith (WR)	Strategic planning, ranger, area management, assets management, planning, executive management	13
Far West/ Broken Hill (FW)	Strategic planning, ranger, area management, assets management, fire and incident management, World Heritage conservation.	13
Total		208

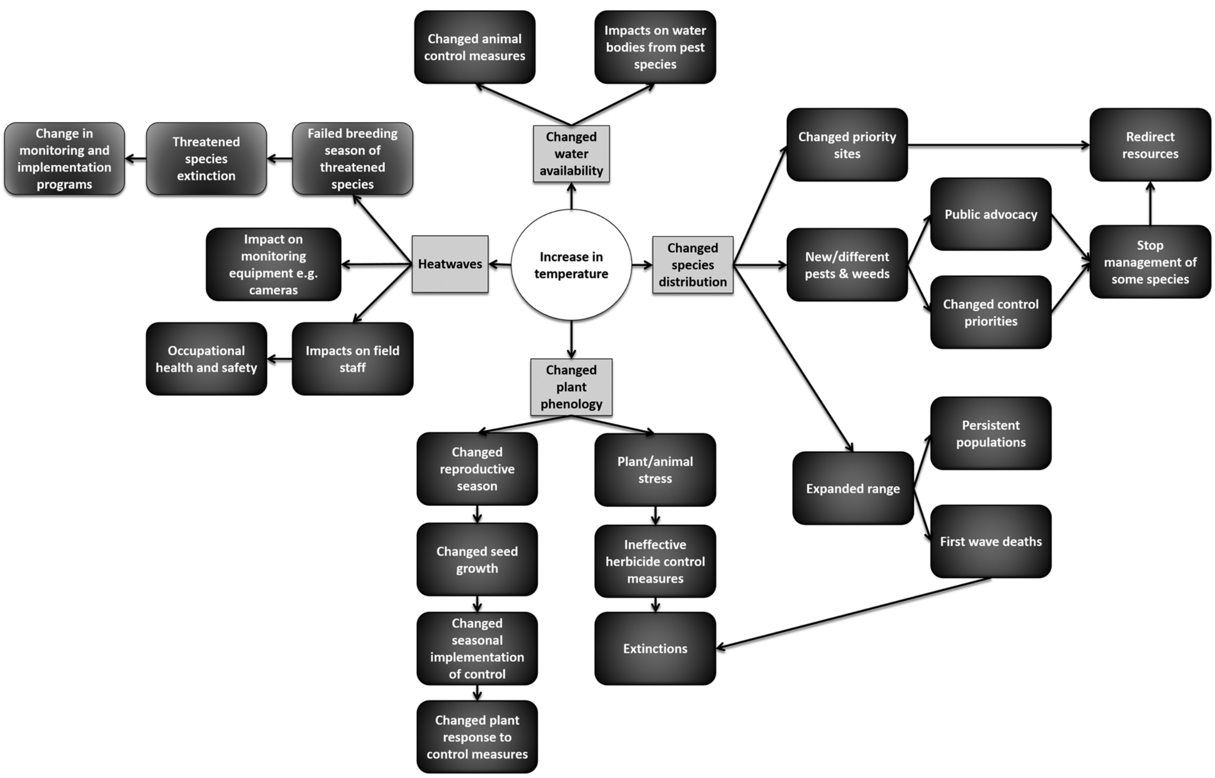

Fig. 2. Example of direct (light grey) and flow-on (dark grey) impacts of increasing temperature on pests and weeds functional area.

Through the combination of plenary discussions and small group exercises, participants completed three main tasks:

(1) Identification of key park values. For specific locations within the selected region, key park 'values' were identified on region-wide geographical maps. Values could be broadly defined, for example, as a species of importance to biodiversity, a significant built asset (NPWS building, infrastructure or heritage asset), a site of cultural importance (indigenous or non-indigenous) or a rare landscape feature.
(2) Assignment of current risk and management actions. For selected key values, a level of current climate risk was assigned based on the assessment matrices developed in the functional workshops as appropriate (that is, the park assets matrix was used for buildings and infrastructure values, nature conservation matrix for biodiversity values and so on). Participants then listed the management actions currently implemented to protect the value. Using the adaptive pathways appropriate to the function of the value, participants then compared their list against the comprehensive suite of actions identified as potentially appropriate at the specified risk level.
(3) Identification of future risk and management options. Finally, participants were asked to consider the change in management

required should the climate risk to the value rise to the next highest category. For example, the actions identified as required to manage a medium of level of risk to a coastal shell midden were modified to now account for a high risk level.

The information generated in the regional area workshops was collated into a database and formed the basis for a series of case studies of adaptive management under climate risk that encompassed most of the climate-threatened value-types throughout NSW NPWS reserves. It was envisioned that the database could be used as a resource for knowledge sharing about management options across the NSW reserve system and to inform the consideration of climate change in the development of management plans (Fig. 1).

This project produced a large qualitative dataset. The results presented below focus on selected examples of outputs from stages of the process and from individual functional areas to illustrate its efficacy as a tool for eliciting local knowledge of management options and as an input to strategic planning of multi-functional public reserves for climate change.

3. Results

3.1. Visualising impacts

Fig. 2 presents a typical example of impact visualisation from the functional area workshops. In this instance, the effects of changes in temperature on pest and weed (PW) functional area were considered: gradual increases in temperature; extreme heat events, and changed fire frequency and intensity. The direct effects of extreme heat events included greater intensity and duration of heat-waves; changes in water availability; changes in the distribution of species and changes to development patterns of plants (such as time of flowering and seed set) (Fig. 2). Each of these direct effects is associated with a chain of ‘downstream effects’ of varying complexity. For example, changes in the distribution of species may increase the invasiveness of pest and weeds and lead to an expansion of their population size or range. Further indirect impacts include the emergence of new pest and weed species and possible extinction of threatened species, which may in turn lead to a reprioritisation of organizational monitoring and implementation programs and program budgets. Other indirect effects include changes to the reproductive season of plants resulting in the need to alter seasonal implementation of control measures and species responses to them. These changes may further affect fauna that rely on flowering plants and seeds for food, such as pollinators or nectivorous bird species, which in turn may cause animal stress and lead to localised extinction of sensitive species.

3.2. Key management pathways and interdependencies

Key event chains were extracted from impact visualisations for consideration of the complexity of actions employed to manage the event, and identification of interdependencies among NPWS functional areas and the public. For example, for the customer experience (CED) functional area (Fig. 3), sea level rise (SLR) that causes periodic or permanent inundation of park assets triggers a complex suite of management actions. In the event of SLR-induced beach erosion or campground inundation, CED staff erect signs and may restrict access to the public. Increased CED resources are devoted to communications to update the NPWS website and social media pages and to manage internal communications with other areas such as on-line accommodation booking services, and park assets managers (PAB). CED manages external communications with the media and park volunteers. Other important stakeholders such as park rangers and external commercial tour operators may also be notified of any cancellation of public tours, for instance, during a high tide event. If Aboriginal artefacts are affected, then NPWS staff notifies Local Aboriginal Land Councils (LALC’s). SLR can also cause damage or loss of assets managed by PAB. Ongoing effects on built assets may require adaptive retrofitting or rebuilding, to improve drainage and divert water away from the asset.

3.3. Risk framing

Of the two components of risk, there was less variation among functional areas in the framing of ‘likelihood’ (or probability); whereas the definition of ‘impact’ (or consequence) varied and was closely related to the role of each functional area. Participants from functional areas unfamiliar with the application of climate change risk to their operational roles initially struggled to define likelihood categories for current climate related events. However, after discussion most settled on a generic framing of likelihood categories routinely used by the fire and incident management functional area as, 1. Rare: theoretically possible but not expected to occur: 2. Unlikely: will not occur in the majority (fewer than 50%) of situations; 3. Possible: equal chance of occurrence or non-occurrence; 4. Likely: will occur in the majority (greater than 50%) of situations; and, 5. Almost certain: will occur in most to all situations.

Table 3 presents the impact categories from climate events as defined by three functional areas: Fire and Incident Management (FIM), Nature Conservation (NC) and Heritage (HTG). FIM defined the impacts of fire in terms of its effects on health and safety of public and staff, environment, and Aboriginal and non-indigenous culture and heritage ranging from little or no impact (negligible) to wide-scale unrecoverable or permanent loss to values of critical importance (catastrophic). NC considered impact not only in terms of species decline but also in relation to the threat to agency resources and effort required to continue its role in biodiversity conservation. HTG defined impact differently for tangible and intangible values. Typically, for tangible values the impacts ranged from little or no loss of place or culture (negligible) to complete loss of values potentially leading to delisting of World Heritage status at specific locations. Across the impact categories, intangible values were progressively diluted ranging from acculturation (adoption of alternative cultures) under minor impact, to complete loss of culture, underpinning cultural identity and spirituality in the landscape at catastrophic levels.

The impact and consequence categories were then used to construct a standard 5×5 (five-colour) risk matrix for each functional area (Cox, 2008) to aid in the development of adaptive management pathways.

3.4. Adaptive management pathways

Fig. 4 depicts adaptive pathways constructed from the range of management actions available to Park Assets Branch (PAB). At negligible risk levels, a single management action was identified: repair and maintenance of built assets. This action spans all risk levels from negligible through to extreme risk although, as risk levels rise, ongoing maintenance and repair of assets would likely be prioritized in terms of costs. Other pathways implemented at the low risk threshold include monitoring, communications, public and staff protection, and improvements to building standards and design. Four management actions, building standards, building retrofits, building replacement and relocation, and asset decommissioning formed a complex interconnected pathway of actions to adapt to the impacts of climate as risk levels rose from low to extreme. This pathway links development of improved building standards and their implementation in asset upgrades with the need for asset replacement and relocation to mitigate risk. The pathway terminates with the closure and decommissioning of assets under extreme risk levels.

For PAB, management effort is greatest at medium to high risk levels as the largest numbers of pathways are in operation to manage risk. This response was common across the range of functional areas.

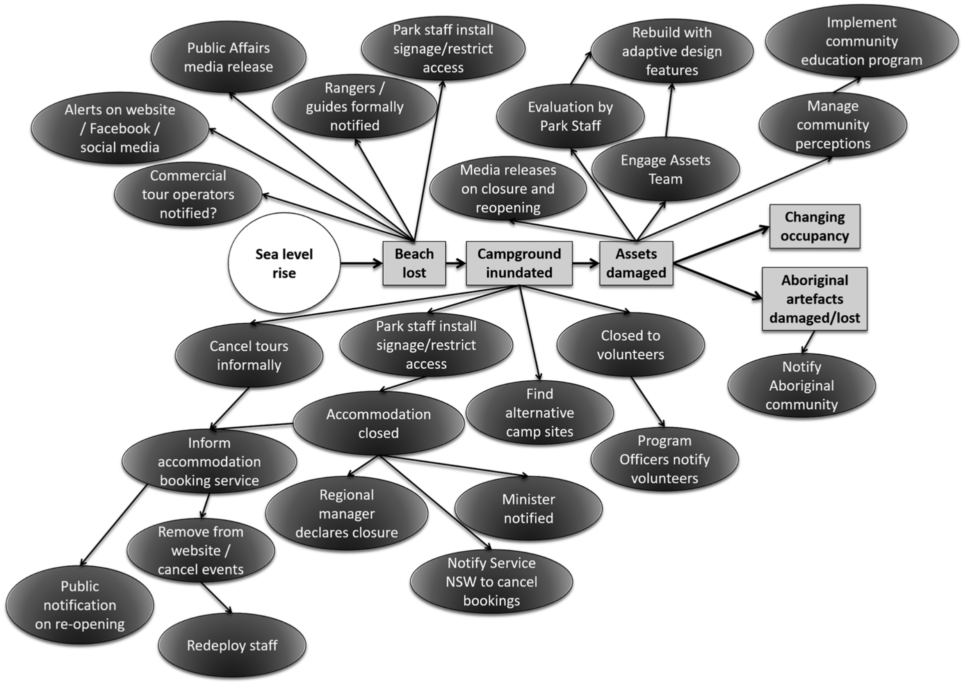

Fig. 3. A key impact chain (light grey rectangles) for the customer experience functional area showing the complexity of management operations/actors (dark grey ovals) involved in response to a sea level rise event (white circle).

Table 3
Framing by selected functional areas of the impact component of risk.

Impact category				
Catastrophic	Major	Moderate	Minor	Negligible
Fire and incident management: Health and safety, environment, Aboriginal and non-indigenous culture and/or heritage				
Unrecoverable / permanent loss in large numbers or of critical importance.	Substantial over a long term to permanent loss	Significant, medium to long term impacts or minor permanent loss	Some impact, recover within a short timeframe	Little to no impact
Nature Conservation: *Species decline, conservation resources and effort*				
Species extinction/ Death of a staff member/ Government dismantles National Parks	Rare/ Significant injury of staff/ Loss of agency credibility	Localised extinction/ minor staff injury / Reduction in resources and funding	Population decline/ Redirection of funds	No detectable impact/ Failure to optimise outcomes
Heritage: *Tangible assets – historic buildings, collections, sites*				
Loss of multiple significant cultural sites and access to sites/ loss of totem animal/ World Heritage site delisted	Substantial loss of sites/ landscape change / loss of historic buildings or collections /WH* site damaged but recoverable	Temporary loss of site access/ place disrespected/ minor or temporary damage to WH* site	Minimal impact on cultural sites/ minor damage to a historic building or collection	Little or no loss of place or culture.
Heritage: *Intangible assets – spirituality, culture and its practice*				
Loss of culture/ underpinning identity/ spirit in the landscape	Lack of interest in cultural practices and knowledge/loss of connection to place	Landscape change but culture continues/ Temporary loss of connection to place	Acculturation – adoption other cultures – dilution of culture	Little or no loss of place or culture.

3.5. Regional workshops: tool implementation

The adaptive management pathways developed in the functional area workshops (Fig. 4) formed a tool to aid regional adaptation planning for climate change. Fig. 5 illustrates the use of the Aboriginal and cultural heritage pathways in a case study to assess management of an Aboriginal coastal shell midden potentially subject to sea level rise. In this case, the current risk to the midden was assessed as low to medium (yellow band in Fig. 5) with generally minimal impact on the site but with some potential for damage and temporary loss of access during king tide events. This level of risk called for management actions that included monitoring of impacts, recording of stories and culture camps to conserve intangible aspects of heritage, and repairs to site damage. These actions were then compared against the current management to determine any additional actions that should be in place now at the site.

Future management needs under climate change were then considered as the list of actions required to be implemented to manage the site for the next highest risk category, that is medium-high (orange band in Fig. 5). At this level, the midden is at risk of severe damage or loss with concomitant loss of cultural connection and cultural practices associated with the site, and change in the surrounding landscape. Management at this risk level requires additional actions that may include deeper consultation with the Aboriginal community, cultural storyline confirmation at another location, alternative methods to convey cultural meaning (e.g. geo-spatial applications for story telling) and possible site ‘ruination’. The list of additional future actions, in combination with frequency or level of impact to the value, could then be factored into planning at this site. This task was completed for a range of value types in selected National Parks to better understand future management effort from local to regional scale.

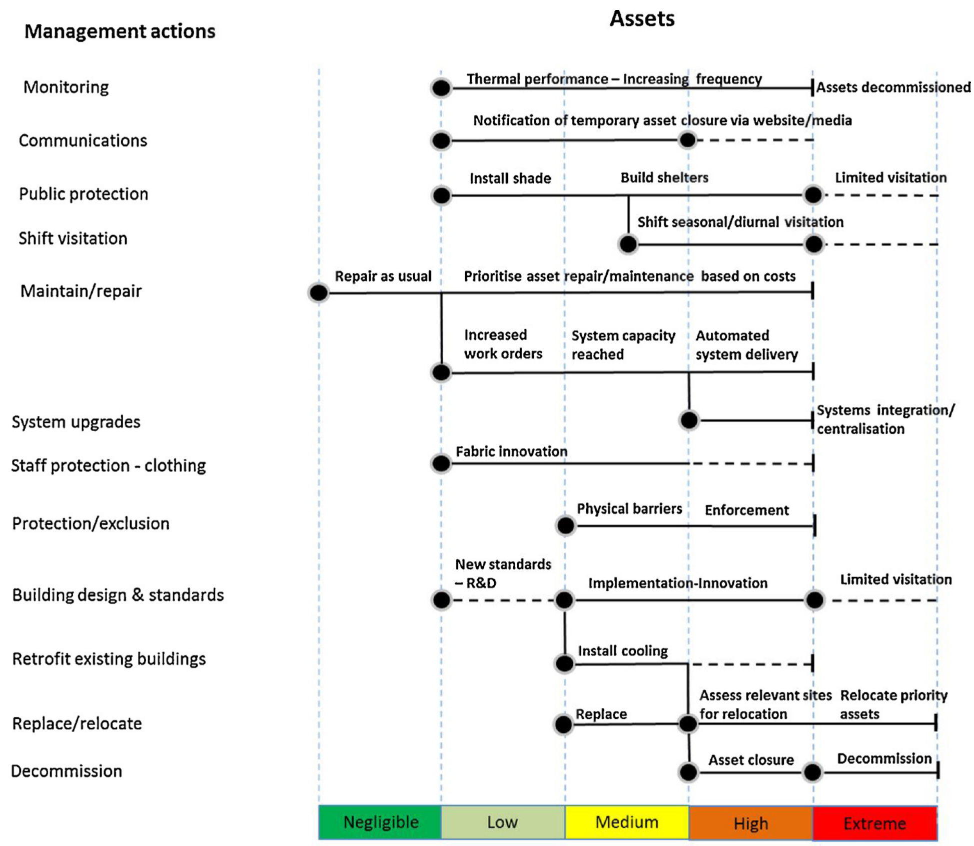

Fig. 4. Example of adaptive management pathways under dynamic risk developed for park assets functional area. Black circles represent the beginning of a pathway or a disjunction along a pathway. Dotted lines uncertainty about the continuation of a pathway at a certain risk level.

4. Discussion

The concept and application of knowledge co-production has evolved into a model of good practice to integrate science and policy in decision-making for climate change (Cash et al., 2006; Mastandrea et al., 2010). Lemos and Morehouse (2005) defined a model of knowledge co-production for climate assessments as the interaction of three components - interdisciplinarity, interaction with stakeholders and production of usable knowledge – with successful application achieved through an appropriate ‘fit’ between the state of knowledge production and application, disciplinary and personal flexibility, and availability of resources. Our engagement with NSW NPWS suggested that it is arguably one of the most complex areas of government service delivery. Its mandate stretches across a range of scales and levels (e.g. Cash et al., 2006): spatial, temporal, jurisdictional, institutional and managerial. In addition, the agency and its staff are integral to various social networks, internal and external to the organisation, and draw on diverse knowledge domains to perform functions for society. This complexity is heightened in strategic planning for the current and projected impacts of climate. We believe that the process we employed in this study is an example of knowledge co-production because it:

- aimed specifically to gather, integrate and disseminate information relevant to regional planners and decision makers with the users of that information (demonstrating ‘fit’);
- was co-designed with agency staff to ensure it was culturally appropriate (demonstrating flexibility); and,
- incorporated close consultation with senior NPWS decision-makers to ensure their support for and encouragement of participation by agency staff (securing resources).

Moreover, our approach ‘flips’ in orientation between phases combining a top-down-predictive approach to understand high level agency functions (functional area workshops) with a bottom-up-diagnostic approach to understand agency operations (regional workshops), thereby also satisfying contemporary guidance on good practice for adaptation planning (Jones and Preston, 2011, Mastandrea et al. 2010).

Two complementary techniques were employed in the development of the planning tool: adaptive pathways and risk assessment. The adaptive pathways concept emerged from the fusion of research on adaptive policymaking (e.g. Walker et al., 2001) with that on adaptation tipping points and policy pathways (e.g. Kwadijk et al., 2010) to support robust decision making under uncertainty. Uptake of the concept has been rapid and pathways approaches have been applied in a variety of contexts and forms (Maru and Smith, 2014), in particular for aspects of climate adaptation planning including health (Few, 2007), energy (Ren et al., 2011), infrastructure (Smith et al., 2011), natural disasters (Rosenzweig and Solecki, 2014), and regional strategy (Jacobs et al., 2016). In our process, pathways were explicitly linked to management practices in each NPWS functional area. When viewed collectively, these sets of actions expose the complexity facing public reserve managers in attempting to navigate the array of possible management options at specific sites with multiple values (such as national parks).

While incorporation of risk assessment in adaptation planning is recommended (Jones and Preston, 2011) its achievement, in practice, can be problematical. The difficulty people face in understanding uncertainty in relation to statistical probabilities is well documented (Lee et al., 2015, Pidgeon and Fischoff, 2011) and the formation of human risk perception is complex and multifactorial (Helgeson et al., 2012, Hulme, 2009, van der Linden, 2015). In addition, the use of standard likelihood-consequence risk matrices is contentious among quantitative risk researchers. These matrices, particularly where they are used to rank options, have been criticised as both mathematically dubious (Cox,

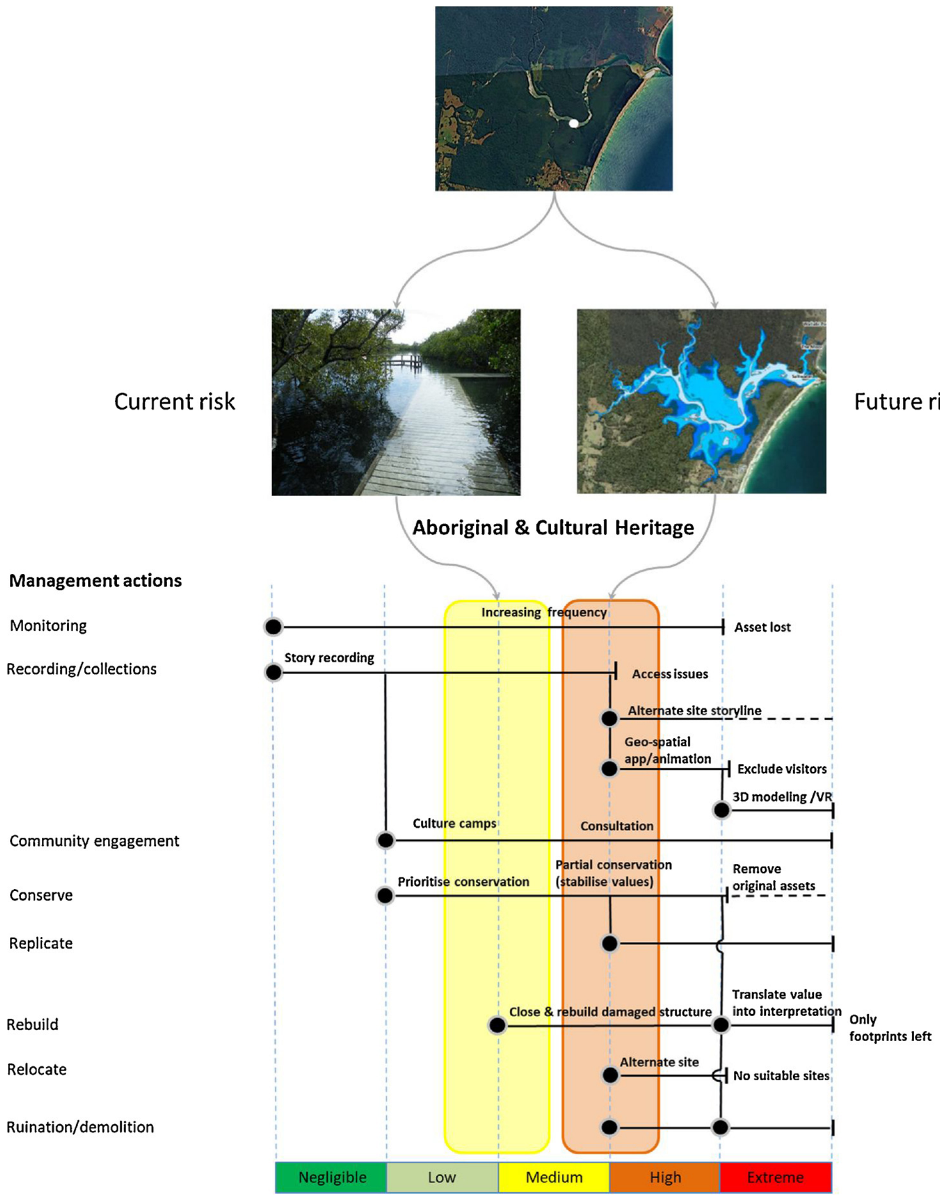

Fig. 5. Adaptation planning tool for 'values' in a national park utilising local knowledge of current climate impacts, local climate projections and available management options under dynamic risk. Aerial images from Google Earth. White dot is the hypothetical location of a shell midden potentially affected by future sea level rise.

2008) and subject to often wide variation in assignment of ratings owing to differences in worldviews, beliefs and psycho-social factors among individual risk assessors (Ball and Watt, 2013). However, we used a qualitative approach to development of a standard risk matrix from expert-derived heuristics, which proved useful as a device for workshop participants to examine future management scenarios without the complexity of detailed climate projections and statistical probabilities. Incorporation of simple risk heuristics facilitated the conversion of the lists of management actions into an adaptive planning tool because it revealed the need for practices to evolve within individual pathways (for example, changes in the way monitoring is conducted) and of discontinuities in pathways requiring a change in the selection of actions under heightened risk. It is important to recognise that at sites where multiple value types are co-located it is possible that multiple risks are in play (for example at a heritage site that encourages heavy public visitation requiring extensive interpretive signage). This again reflects the complex operational realities of the NPWS.

Anticipatory action by management to avoid exceeding disruptive thresholds of change is generally implicit in adaptation planning processes (Kates et al., 2012) and is a concept central to social-ecological resilience theory (Nelson et al., 2007). Two types of thresholds have been identified (Lorenzoni et al., 2005):

- Type 1 thresholds relate to slow changes in climate that may eventually result in system damage and are amenable to incremental approaches to adaptation.
- Type 2 thresholds relate to abrupt or catastrophic changes in climate that lead to 'dangerous' system impacts unacceptable as a consequence of their scale and irreversibility and which call for transformative responses.

Our process attempted to recognise both types of thresholds by presenting future projections of average temperature and rainfall and also drawing on management experience of past extreme events (such as king tides, east coast low storms, and bushfires). We deliberately focused on management triggered by incremental rather than abrupt

change in risk, framing adaptation planning in the current practice and lived experience of participants to overcome institutional inertia (Lawrence and Haasnoot, 2017). However, when viewed holistically across all functional areas, our approach indicates that management effort will increase as climate risk rises becoming greatest at medium to high levels of risk across all regions. Therefore, government will need to respond to increased demand for resources, for better targeting of those resources, and for management innovation in how resources are deployed. Within the NPWS, public reserve management will need to plan for Type 2 thresholds. Kates et al. (2012) suggest that anticipatory transformational adaptation needed to respond to these thresholds may be difficult to implement because of uncertainties about risks and benefits, the high costs of transformational actions, and institutional and behavioural actions that tend to maintain business as usual. Our discussions with participants also suggested that issues of scale may become increasingly important in planning for transformation. For example, at state-scale the need for negotiation with the community around the prioritisation of values that can be conserved and the acceptability of conservation methods (e.g. in situ versus ex situ) was an issue canvased during our workshops. At region-scale, the capability to anticipate the necessary surge in intervention was considered critical under a range of extreme climate events that, as risk levels rise, may simultaneously affect not only parts of NSW but all of Australia. Finally, at local-scale, transformational adaptation will require NPWS staff to remain open to, and be supported in, the adoption of new ways of working to ensure scarce resources are used most effectively.

5. Conclusions

Combining risk assessment with an adaptive pathways approach explicitly linked to management actions proved a useful way to engage a broad range of decision makers in an area of government that is, arguably, one of the most complex, climate sensitive and potentially contentious for service delivery. We believe the process not only makes a significant contribution as a strategic planning tool for climate change adaptation in public sector conservation, but also provides further empirical evidence to support the importance of co-production of knowledge at the policy-science interface (Lemos and Morehouse, 2005).

The value of an engagement strategy such as the one used in this study lies, at least in part, in evaluation of participant satisfaction with the process and outputs, the subsequent use of the information generated and, ultimately, in the demonstration of a change in organisational thinking. Participant evaluation of the process collected at the end of each workshop indicated that a clear majority (90%) of respondents agreed that they had an opportunity to participate and input into the discussion. This coupled with the high levels of attendance and positive feedback on the process gives us confidence in the robustness of our findings.

Since the delivery of the workshops, this process has been introduced to a variety of operational and strategic planning contexts in NSW Government including long-term strategic planning for water, marine estate and Aboriginal land management. At time of writing, for NPWS, this process has contributed to the development of a draft Adaptation Strategy that sets out 4 main actions. These include:

1 A pilot project for including adaptation triggers into the NPWS operational systems;
2 A pilot project for including dynamic risk pathways in strategic planning, and formal Plans of Management for a priority park;
3 Development of a comprehensive strategy for communicating adaptation decisions of NPWS to NSW communities; and,
4 Continuation of support for Aboriginal Heritage risk management through the delivery of adaptation workshops to Aboriginal communities of joint managed parks (New South Wales Aboriginal Land Council, 2016).

In addition, State of the Parks reporting (New South Wales Government, 2015a,b) will now include more detailed climate change impact reporting to track recognition of specific climate change impacts (fire, floods, storms, SLR) rather than a generic category of ‘climate change’ as an impact. We believe these initiatives by the NSW Government are indicators of the utility of the information generated and of a change in organisational thinking that is attributable to our workshop process.

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